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► To cite this version:

M. Di Giacomo, B. Ducoudret, P. Baret, J.C. Deroy. The test bench for the power amplifiers of the SPIRAL-2 SC LINAC. 13th International Workshop on RF Superconductivity, Oct 2007, Beijing, China. pp.717-720, 2007. in2p3-00413954

HAL Id: in2p3-00413954

<https://hal.in2p3.fr/in2p3-00413954>

Submitted on 7 Sep 2009

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THE TEST BENCH FOR THE POWER AMPLIFIERS OF THE SPIRAL-2 SC LINAC

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Abstract

The high current driver accelerator of the SPIRAL 2 project uses independently phased SC resonators working at 88 MHz. Solid state power amplifiers equipped with circulators are foreseen to drive the cavities with widely ranging conditions of beam loading. These power devices are developed by industrial companies and a test bench has been studied and manufactured to test the prototypes, to commission all the units before their installation on the accelerator and to be used to test repaired modules. Even if designed to be used at 88 MHz, the test bench can be used at higher frequencies too. The poster describes the test bench as well as the results on the first amplifiers bought for the cryomodule power tests.

BEAM LOADING AND POWER REQUIREMENTS

The Spiral 2 driver [1] will accelerate ion beams ranging from few tenths of μA to several mA, corresponding to a wide range of beam-loading. A fixed coupler is foreseen for the SC cavities for reliability reasons, with $4.5\text{E}5$ and $1.2\text{E}6$ nominal Q loaded factors for the low and high beta families. These values correspond to overall optimal matching conditions at maximum beam loading.

Beam dynamics simulations [2] at maximum deuteron current give the amount of beam loading of each cavity as shown in Figure 1 .

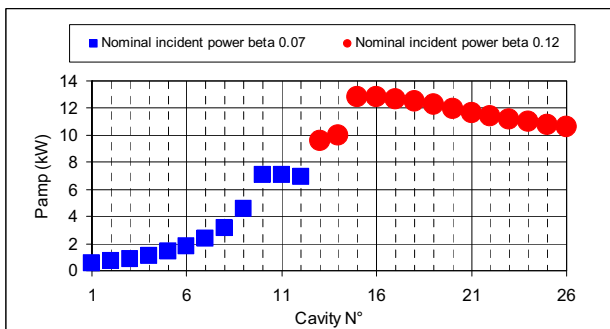


Figure 1: Beam loading along the SC linac cavities for a deuteron beam of 5 mA.

Taking into account feedback margins and losses in the lines and circulators, 10 and 20 kW amplifiers are required for the two families.

These amplifiers have to stand high reflected power. Low intensity beam operation (negligible beam loading) typically requires 25% of the nominal power, as shown in Figure 2 where the amount of power required for the power tests of the cryomodule prototypes at different field levels is plot.

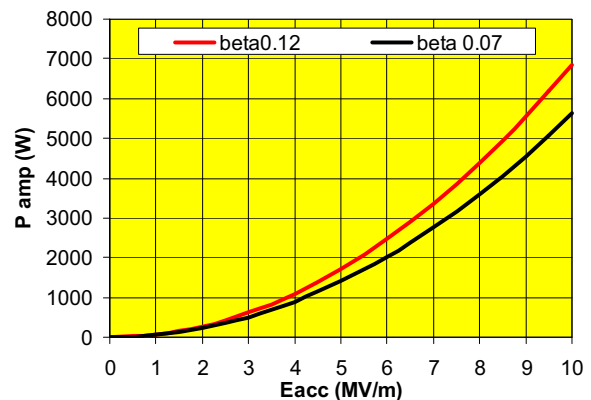


Figure 2: Power requirements for the power test of the cryomodule prototypes

This RF power being totally reflected, we chose to use a 10 kW circulator behind the amplifier.

POWER AMPLIFIERS FM MARKET

One of the reasons for which 88 MHz was chosen as the operating frequency for Spiral 2 is the possibility to take profit of the power equipment industrially developed for the FM market.

Solid state amplifiers are more and more used in FM application, offering higher flexibility then tube ones. Nevertheless, 20 kW and CW (continuous wave) operating mode into high mismatched load are not standard applications and both items required some development to be achieved.

Standard devices are air cooled. Water cooling reduces the dimension of the amplifier and increases the life time.

TESTS BENCH

A 20 kW test bench was then developed to study prototypes built by industrial companies and to achieve the experience to define the final requirements for the linac amplifiers.

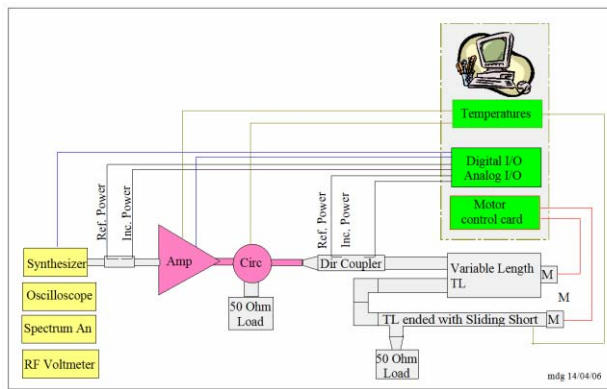


Figure 3: Test bench scheme

Figure 3 shows the functional scheme of the tests bench.

A 50 ohm load in parallel to a quarter wave line equipped with a sliding short acts as variable VSWR device.

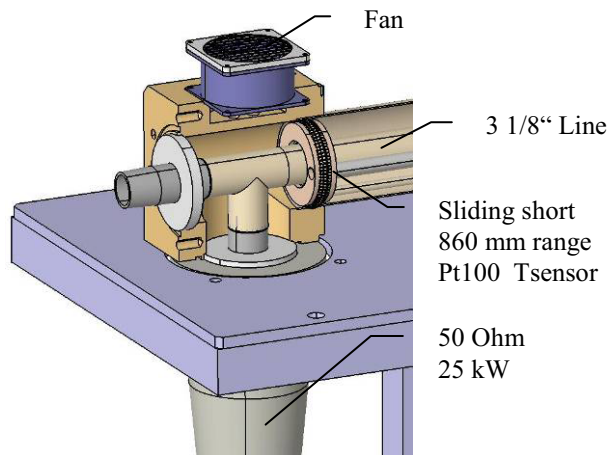


Figure 4 : mechanicals details

To be used at 20 kW, the device is manufactured with a 3 1/8" transmission line and air cooled.

A PT 100 temperature sensor monitors the temperature at the short circuit contacts to protect the device. The Tee block is machined in solid copper while the 50 ohm resistor is a standard coaxial load, dimensioned for 25 kW.

The phase shifter is an industrial device from Mega Industries Inc, able to produce a 250° phase rotation at 88 MHz.

The computer control uses a graphic interface developed with LabView and USB, GPIB and compact field point cards to interface the motors commands and position indicators, to read temperatures, and to interface the synthesizer and other instrumentation.

Figure 5 shows the whole tests bench with the variable VSWR device in front, the phase shifter behind, the computer control in the background. The 20 kW amplifier and circulator are also visible.



Figure 5: Test bench installation

10 AND 20 KW PROTOTYPES

Our first prototyping efforts during the design study phase concerned 1 kW amplifiers, based on four, 300 watt elementary modules combined together. Each module was equipped with a 500 watt circulator but the amplifier could only sustain 50% of reflected power due to thermal dissipation.



Figure 6: air-cooled 1 kW rack with and without circulators (@ ECRESO)

Other tests on standard 1 kW amplifiers equipped with an external circulator showed that this solution is more flexible and less expensive at 88 MHz. It implies no need to oversize the output stage components and the combiners to sustain high reflected power and it leads to more compact systems.

3 kW amplifier

Availability of new more powerful MosFets and water cooling gave recently the possibility to have 3 kW compact racks based on the scheme of Figure 7.

The single RF pallet contains two SD2942 push-pull Mosfets, combined by a Wilkinson lumped circuit and able to deliver up to 800 W in class C operation.

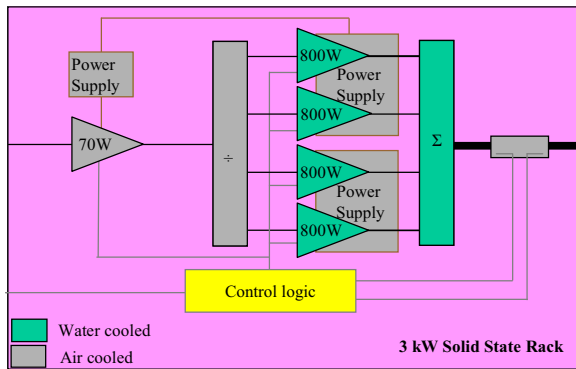


Figure 7: Schematics of the 3 kW rack.

Four of these pallets are combined by a 4 way, Wilkinson strip-line circuit. The RF pallets and the 4-way combiners are water cooled. The rack includes a 300 W preamplifier whose output power is limited to avoid over driving of the final stages.

Two power supplies bias the 4 pallets with independent readings of the four voltages (48V) and currents (<20A). The driver can be biased via any of the two units, that allowing operation, at reduced power, even when one power supply fails. The power supplies are equipped with their own fans, which let the rack be operated stand alone.

Significant mechanical optimisation led to the availability of a 3 kW rack weighting less than 30 kg, which we consider as a weigh goal for easy maintenance.

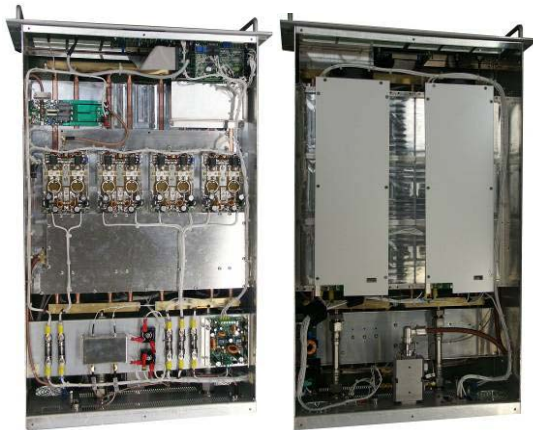


Figure 8: water cooled 3 kW rack

Mains presence, temperature threshold, reflected and driving powers, external authorisations are interlocked by a PLC. Pallets parameters, input signal level, output direct and reverse powers, cooling plate temperature are monitored on the front face and available through a RG 485 link with a Jbus protocol.

10 kW and 20 kW amplifier

Combining four of these racks gives a compact 10 kW amplifier that can be contained in a 650x1000x1900 cabinet. In air hybrid 3dB combiners are used for highest efficiency.

The cabinet also contains a 3 W driver, the control logic, the output directional coupler, the mains switches,

the watercooling distribution and a fan for complementary aircooling.



Figure 9: 10 kW cabinet and 6 and 10 kW hybrid combiners.

Two similar cabinets are combined to produce a 20 kW amplifier. The present 20 kW combiner is oversized and test with a smaller one still have to be performed.



Figure 10: 20 kW combiner

TEST RESULTS

Test bench

The test bench has been used up to 15 kW at maximum VSWR, and up to 20 kW at lower mismatching levels. More tests will be performed as soon as the 20 kW circulator is available. The response of the variable VSWR device fits quite well the expected curve as shown in figure 11, and the phase shifter provides 250° at 88 MHz.

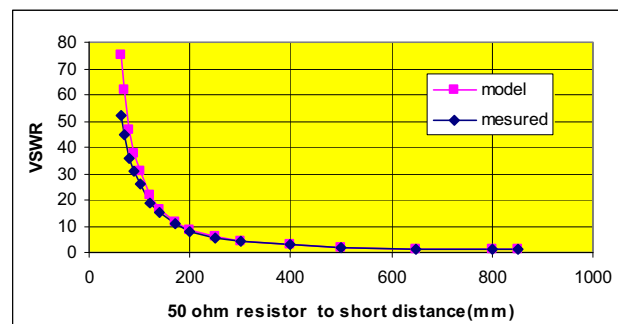


Figure 11: variable VSWR device response (88 MHz)

Amplifiers

The 3 kW racks are set to give 2.8 kW and stand 10% of reflected power. Efficiency of the single pallet depends on the working point. Using $V_d=48V$ and $V_g=0.8V$ it is around 78%. Combination of the four stages reduces this value to 74% for the 3 kW rack. The splitters and combiners are balanced at ± 0.1 dB as well as the driver outputs while no special care (unless bias figures) is taken for the 3 kW racks by the moment. Figure 12 shows the maximum and minimum responses of the two sets of racks of the 20kW amplifier; the rack contribution is therefore well balanced at maximum power only.

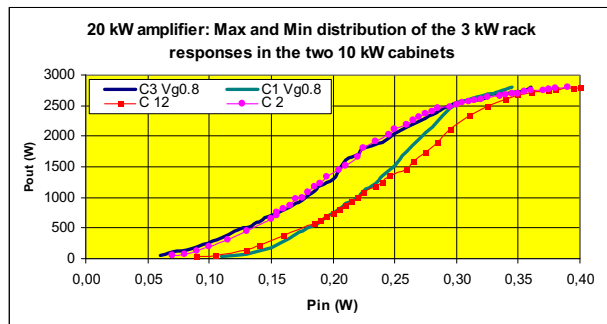


Figure 12: response scatter of the 3 kW racks

Harmonics are well below 35 dB at the 10 kW output and even less after the 20 kW combiner. Long time tests have been performed on matched and mismatched loads, to monitor the output power stability and overall reliability. Both the 10 and 20 kW amplifiers reach nominal power and grant 1% stability during a 24 hours test. A few troubles on the power supplies and two Mosfet failures append during the first few weeks of tests. The most of these problems arrived while we were searching for the maximum level of reflected power the amplifier could stand at a given phase. This could mean that the rack protections are not reliable at any phase yet. Figure 13 shows the reflected power monitored by each rack at constant (1.5) VSWR vs the position of the phase shifter: the sum of the monitored values is not constant which clearly indicates a measurement problem. Nevertheless more measurements will be done in the next weeks.

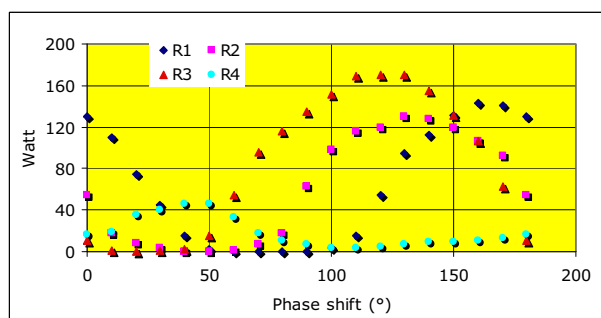


Figure 13: reflected power on the 4 racks, @ 10 kW output power, VSWR=1.5.

CONCLUSION

The test bench for the amplifiers and other RF power devices of the Spiral 2 SC Linac is ready and let us commission the first three power amplifiers required by the incoming cryomodule power tests.

A compact, water cooled, high efficiency, and easy to maintain 10 kW amplifier which achieved the required parameters have been developed by an industrial company of the FM market

Useful experience has been acquired on the critical elements of solid state amplifiers which will help in the preparation of the call for tender for the serial production.

ACKNOWLEDGEMENTS

The authors would like to thank, in particular, Y. Merrer of the LPC – Caen Laboratory for mechanical design of the variable VSWR device and P. Toussaint and the Ganil workshop group for its manufacture and assembly, They are also grateful to D. Allal and L. Menager of the Ganil accelerator division RF group for their participation to test bench assembling, and to Ti Ruan of the Synchrotron Soleil for useful discussions on solid state amplifiers.

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